PRESSURE DISTRIBUTION IN RELATION TO THUNDERSTORM OCCURRENCE ON OREGON AND WASHINGTON NATIONAL FORESTS

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[Pacific Northwest Forest Experiment Station, July 1935]

INTRODUCTION

Weather forecasting is simplified if a definite relation can be found between local weather and the large-scale picture of meteorological conditions given by a synoptic chart. Investigations of the conformity of various meteorological phenomena to certain types of pressure distribution over large areas have been carried on since the early days of synoptic meteorology. One of the earliest classifications of the various types of pressure distribution which repeatedly appear on any series of weather maps was made by Abercromby (1) for the northeastern Atlantic Ocean and northwestern Europe. Reed (7) has discussed the recurrence of pressure types over the northeastern Pacific Ocean and adjacent land areas.

The thunderstorms of the United States have been classified by Humphreys (5) according to the disposition of the isotherms and isobars on the weather map. The three conditions, any one of which he states may produce the vertical temperature gradient required for the development of rapid convection giving rise to thunderstorms are: (1) Strong surface heating, especially in regions of light winds; (2) the overrunning of one layer of air by another at a temperature sufficiently lower to induce convection; (3) the underrunning and consequent uplift of a saturated layer of air by a denser layer.

Alexander (2), in 1927, made a study of the relation between thunderstorm occurrence in the State of Washington and types of pressure distribution over the Pacific Coast States. The four types of pressure configuration which he identified bore a definite relation to those outlined by Humphreys (5).

Stevens (8) has developed a series of correlations between 8 a. m. eastern standard time barometric pressures, vapor pressure, 24-hour barometric pressure change at selected stations, and the extent of thunderstorms in western and central Oregon. Pressure differences between various stations were used as an indication of a north-south trough of low pressure, or the presence of a cyclonic disturbance to the north of the region. Vapor pressure was used to indicate whether moisture conditions are favorable for thunderstorm inception. These correlations were intended only as a supplement to knowledge of the general pressure distribution conducive to thunderstorm development, and other factors such as free air conditions.

Morris (6) has focused attention on the frequency and behavior of thunderstorms and number of forest fires caused by them in the mountainous areas of Oregon and Washington. It was shown that thunderstorms consti-

tute the greatest single cause of forest fires on the national forests of that region. Since 1924 exhaustive reports of thunderstorms from Forest Service lookouts have been collected and plotted, with the result that there is now available an immense volume of data on their frequency, tracks, hours of occurrence, etc. These have been summarized (6) for the period from 1925 to 1931.

The forecasting of these destructive agents is a problem of major importance in this region during the dry summer season. A familiarity with any correlation between thunderstorm occurrence and the general pressure distribution shown on the synoptic chart is certain to be a valuable aid in the prediction of such phenomena. Gray (4), in a study of California thunderstorms, has stated that "* * * isobaric charts must remain of paramount importance * * * to the forecaster."

The purpose of the present report is (1) to relate the basic information furnished in Morris' report definitely to forecasting problems, and (2) to carry on the analysis begun by Alexander, enlarging its scope to include the State of Oregon and making such revisions and additions as seem necessary in the light of the increased information available in recent years.

PRESSURE TYPES

In examining the a. m. and p. m. synoptic charts for the 10-year period 1925 to 1934, four distinct types of pressure distribution were identified as giving rise to thunderstorms on the national forests of the Pacific Northwest. These are definitely related to the types described by Humphreys and Alexander. Listed according to their frequency and forecasting importance they are: Type I. Trough; Type II. Cyclonic; Type III. Transition; Type IV. Border.

CHARACTERISTICS OF THE PRESSURE TYPES

Type I. Trough thunderstorms.—This type corresponds to Humphreys' (5) "low-pressure trough between adjacent high-pressure areas", and at times to his "regions of high temperatures and widely extended, nearly uniform pressure." It is similar to Alexander's (2) "anticyclonic or trough storm." Low pressure overlies the interior portions of Oregon and Washington between areas of high pressure over the northeast Pacific Ocean and the Rocky Mountain region or the Great Plains. It is the "Northerly Type" of pressure distribution described by Reed (7) as typical of the northeastern Pacific in summer. Frequently it is almost the same pressure condition identified by Abercromby (1) as a Col—a region of relatively low

pressure between adjacent areas of high pressure, a region of light, variable winds and unsettled weather especially productive of thunderstorms.

During the prevalence of a type I pressure distribution a number of the requirements outlined by Brooks (3) as necessary for the development of local, convectional thunderstorms are admirably fulfilled. There are, for example, large volumes of warm air available because of light, variable surface winds; and a lack of a marked diversity in the air movement aloft, due to a general stagnation of conditions. Table 1 illustrates the extremely light winds observed at high levels over the Pacific Northwest on a day of thunderstorms during type I pressure conditions. Violent convection results because these conditions are ideal for the air at the surface to become hot

(fig. 1). It is a northward extension of the semipermanent Colorado Valley "heat" LOW, and usually sets in over southwestern Oregon, extending slowly northward west of the Cascades over a period of several days. Under these conditions abnormally high temperatures are ordinarily reported from the interior portions of Oregon and Washington which lie west of the Cascade Range. In the 10-year period, 1925 to 1934, no "general" and few "intermediate" storm days were caused by type Ia in the State of Washington, but it was an important cause of "intermediate" storm days in western and central Oregon. The thunderstorms developed seem to be the result of local convection. They usually develop shortly after a very dry mass of air moving from the north or northeast at high levels is replaced, or beginning to be replaced, by air
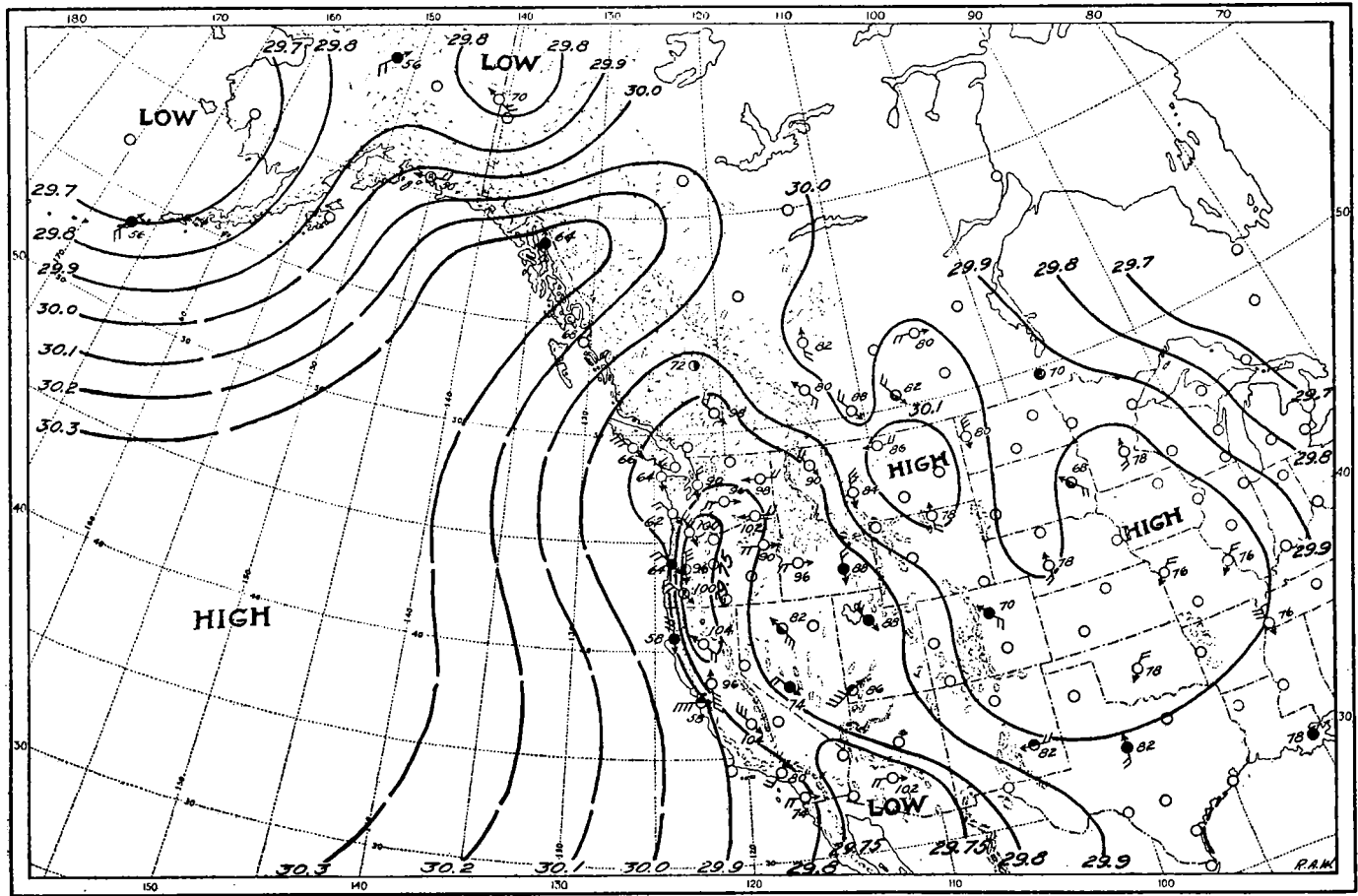

FIGURE 1.—July 28, 1927, 5 p. m. (One hundred and twentieth meridian): Conditions favorable for the development of "trough" thunderstorms of type Ia in Oregon and Washington.

relative to that aloft. Other factors influencing local convection, present as a rule during type I conditions, are clear mornings, permitting rapid surface heating, a dry condition of the ground, and a supply of cold air at high levels. The cold air aloft is due partly to clear, calm nights favoring rapid radiation, and partly to the presence of a current of Polar Pacific air, or transitional Polar Pacific air [1] over most of the Pacific Northwest at high altitudes in the summer (9).

The "trough" type was found to possess three distinct variations, basically similar, but differing in details, particularly as to the location of the trough. Accordingly, the type was subdivided as follows:

Type Ia.—In this variation of the type the center of the trough lies over the Cascade Range or just west of it

of oceanic origin. In other words, the influence of the continental high-pressure area, with its dry transitional Polar Pacific air, is weakening, while a new mass of relatively moist and cool air is moving in at high levels. A shift of wind above 6,000 feet from northeast or east to southeast and south at Medford is an indication of the beginning of a type Ia condition. Within 36 hours southeast to southwest winds reach northward at high levels to Portland and Seattle, although northwest to northeast winds may continue at the surface. Since this type characteristically sets in at the breaking up of a period of east-wind conditions over the Pacific Northwest, the thunderstorms which it causes are likely to result in large fire losses because the forests in such cases have been thoroughly reduced to tinder dryness by winds of very low relative humidity blowing from the interior for several

[1] The air mass terminology employed by Willett (9) is followed in this report.

days. As thunderstorms of type Ia are usually not accompanied by large amounts of precipitation, each "strike" may cause a fire which will spread rapidly in the dried-out forest. The type generally breaks up with an influx of high pressure from the Pacific. In this case it passes through the transition stage of type III (see below) before being supplanted by high pressure. On the other hand, the trough may be pushed only slightly eastward, in which case a type Ib condition is the result. This may cause a continuation of thunderstorms for an indefinite period. The weather maps of June 10 to 14, inclusive, 1932, illustrate the development of type Ia conditions following a period of interior winds. Those of July 22 to 25, inclusive, 1927, illustrate the type as associated with record-breaking

typical day is illustrated in table 1. Type Ib may develop directly, but it frequently follows or develops out of a type Ia distribution by a mere shifting of the axis of the trough to the eastward of the Cascades. This change brings to an end the hot weather west of the mountains, but by no means an end of thunderstorm conditions there. The type apparently will not definitely break up until a large-scale movement inland of fresh Polar Pacific air takes place, produced either by the appearance of a cyclonic depression at the northern end of the trough which moves eastward, or by a definite inland movement of a portion of the Pacific HIGH. In the latter case the transitional type III stage occurs for a day or two before the definite end of thunderstorms. The weather maps
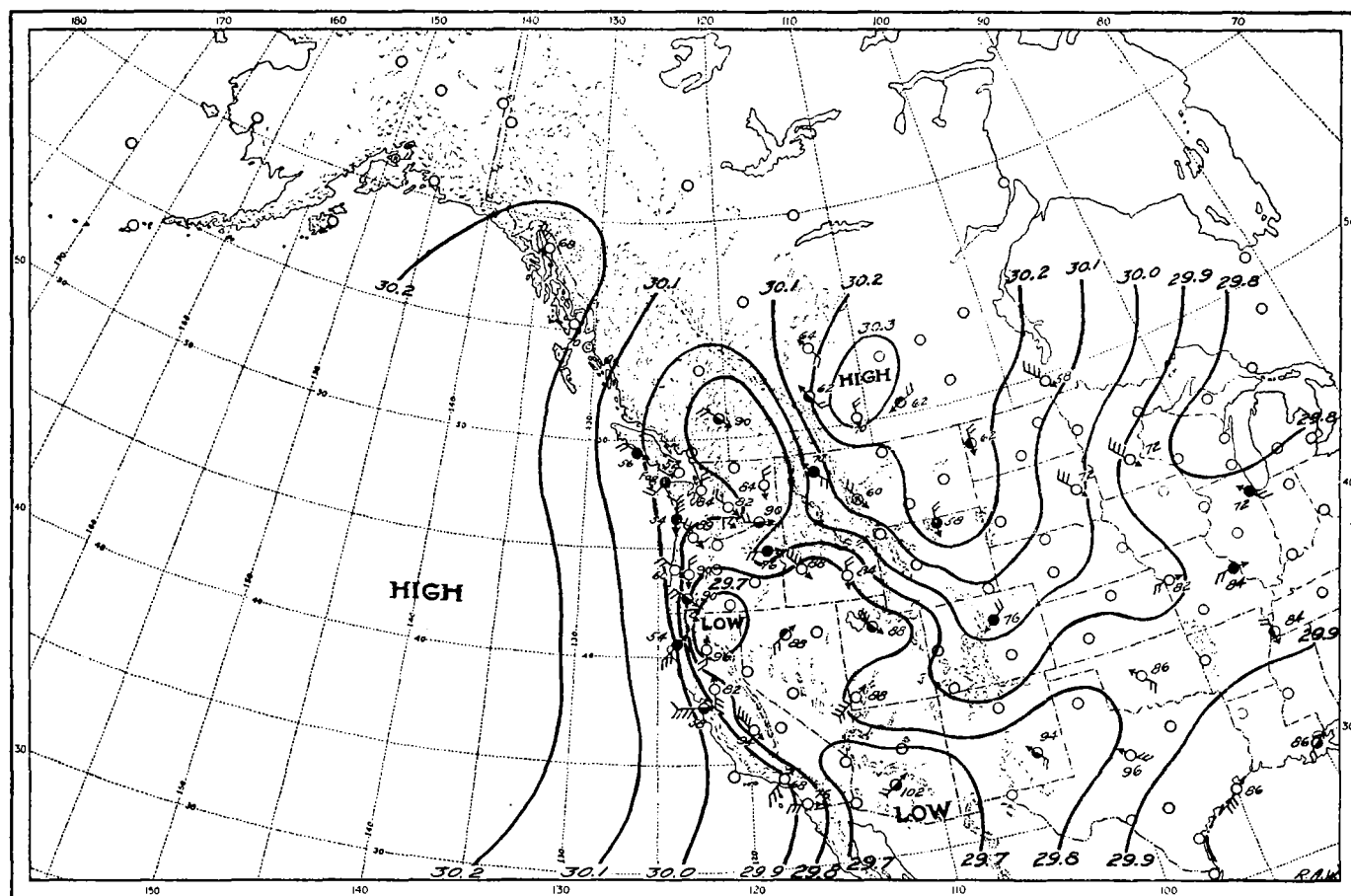

FIGURE 2.—July 31, 1927, 5 p. m. (one hundred and twentieth meridian): Conditions favorable for the development of "trough" thunderstorms of type Ib in Oregon and Washington.

high temperatures at many stations west of the Cascades in Oregon.

Type Ib.—This subdivision is similar to type Ia, but the center of the trough, while west of the one hundred and fifteenth meridian, lies definitely east of the Cascade Range (fig. 2). Temperatures in this case are generally seasonable west of the Cascades and high east of them, and the thermal, as well as the pressure, gradient between North Head and Portland on the p. m. chart is considerably less than in the case of type Ia. It is the typical summer type of pressure distribution and is frequently remarkable for its persistence. Occasionally it endures for 2 weeks without important change, during which time thunderstorms are an almost daily occurrence over a considerable area. Winds aloft at Portland and Medford are usually from south to west above 5,000 feet, while at Seattle they are northwest or west. During periods of pronounced thunderstorm activity, however, winds aloft west of the Cascades are south to southwest at all stations. A

from July 30 to August 3, inclusive, 1927, illustrate a protracted period of type Ib pressure distribution which was productive of unusually large fire losses. Those from July 29 to August 3, inclusive, 1929, are illustrative of another period of great thunderstorm activity. Like those of type Ia, thunderstorms of type Ib are generally of the "dry" type.

TABLE 1.—*Free air wind directions and velocities* [1] *on a type Ib day—July 29, 1931, 3.30 a. m.*

Altitude	Seattle	Portland	Medford	Pasco	Spokane
Surface	SE, 1	S, 13	WNW, 6	NNW, 10	X.
2,000 feet	NW, 10	W, 3	WNW, 6	N, 13	N, 1.
4,000 feet	NNW, 11	NW, 11	SW, 4	N, 17	ENE, 16.
6,000 feet	SSE, 6	WNW, 8	N, 2	N, 16	E, 5.
8,000 feet	SSW, 4	ESE, 2	SSW, 15	ESE, 7	X.
10,000 feet	SSW, 6	ESE, 4	SSW, 16	X	X.
12,000 feet	X	SE, 2	SSW, 18	X	X.

[1] Wind velocities in miles per hour.

Type Ic.—This subdivision is almost identical with Abercromby's (1) definition of a Col. Pressure over Oregon and Washington is relatively low while pronounced areas of high pressure overlie the northeast Pacific Ocean and the Rocky Mountain-Great Plains region. Ordinarily the area of low pressure is ill-defined and not definitely related to the lower Colorado River Valley LOW (fig. 3). It may, however, eventually become so. On other occasions the Col is associated with the northwest quadrant of an area of low pressure in the process of development over the Plateau region. A stagnant condition of the lower levels of the air, with light, variable winds over the Pacific Northwest, is characteristic of type Ic and this condition may extend upward to a considerable height.

points of origin of the lower and upper air masses (5). As Alexander points out, however, in the Pacific Northwest, thunderstorms are more frequent in the southwest quadrant of a LOW. Most of the cyclonic disturbances of the summer season develop inland from the Gulf of Alaska at high latitudes, pursuing a course thence south-southeastward to southern Alberta, whence they move eastward. At times they originate as secondaries over southern British Columbia or Alberta, the parent depression remaining far to the north. In either event, the Pacific Northwest is never within the southeast quadrant of such a LOW. Nevertheless, cold air is drawn in aloft, overrunning the warm air which overlies the surface; and convection is generally sufficient to produce thunderstorms
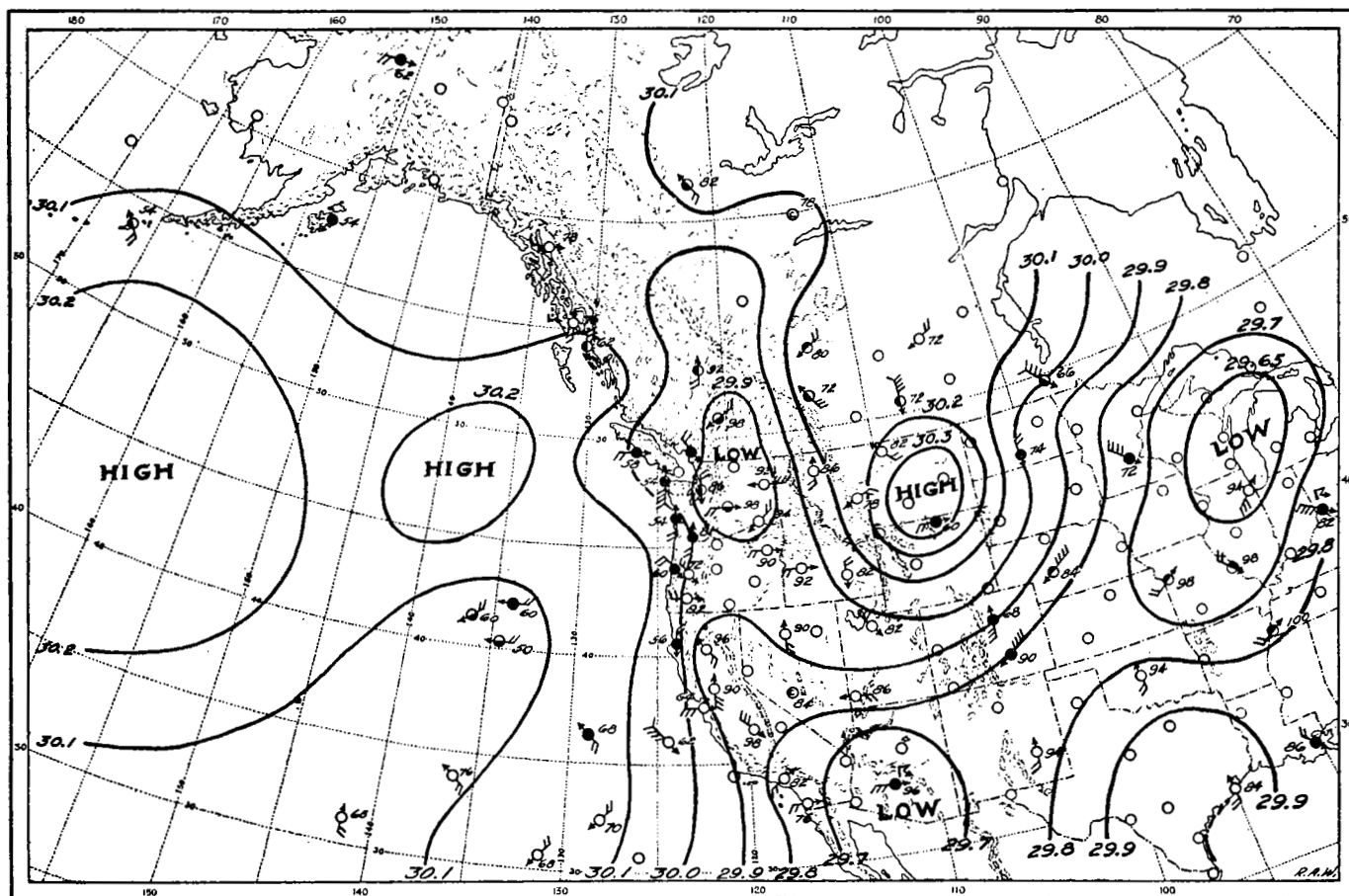

FIGURE 3.—July 12, 1930, 5 p. m. (one hundred and twentieth meridian): Conditions favorable for the development of "trough" thunderstorms of type Ic in Oregon and Washington.

At high levels the winds are moderate to fresh southeast to south at Medford, south to southwest at Portland and Seattle. The type may break up by the Col favoring a northward extension of the Arizona LOW, in which case it merges into type Ib, or by the eastward movement or dissipation of the Great Basin LOW with rising barometers over Oregon and Washington. The weather maps of July 11 to 14, inclusive, 1930, illustrate the Col variation of type Ic. Those of June 1 to 4, inclusive, 1933, illustrate it in connection with the development of a Great Basin depression.

Type II. Cyclonic thunderstorms.—This type corresponds to Alexander's (2) and Humphreys' (5) types of the same name—"the southeast, or, less frequently, the southwest quadrant of a regularly formed LOW or typical cyclonic storm." The cause of thunderstorms in the southeast quadrant of a depression is a rapid decrease in temperature with altitude resulting from the different

in Oregon and Washington in the southwest quadrant of the depression. Type II was divided into two subdivisions, as follows:

Type IIa. The southeast quadrant of a regularly formed LOW or typical cyclonic storm.—In the period under consideration the occurrence of this type was confined to the late spring and early fall. The usual situation is a LOW of considerable extent and energy central a few hundred miles west of the Oregon-Washington coast, moving slowly north-northeastward (fig. 4). Small secondary offshoots pass rapidly inland over the Pacific Northwest, chiefly evident as distortions in the isobars. During this process thunderstorms develop locally in Oregon and Washington. Since they are usually accompanied by considerable precipitation and occur in conjunction with fairly general showers they are not of great importance so far as fire risk is concerned. After a day or two the parent depression begins to fill up rapidly, coincident with an increase

in intensity of a redevelopment east of the Cascades. Soon after the disintegration of the ocean LOW sets in, thunderstorm activity ceases. Winds aloft are south to west at all stations, identical with the upper air winds during periods of cyclonic development in the winter months. An occasional LOW off the Queen Charlotte Islands will produce thunderstorms in Oregon and Washington during the fire-weather season, but such occurrences are very rare. Weather maps of June 13 to 16 inclusive, 1931, and of April 30 to May 2, inclusive, 1932, are admirably illustrative of type IIa.

Type IIb. The southwest quadrant of a regularly formed LOW or typical cyclonic storm.—LOWS which develop as offshoots of low-pressure conditions in the Gulf of Alaska during the summer months pass southeastward or south-southeastward over the Canadian Northwest Territories

wind circulation with increased velocities, and generally passes eastward after a day or two with rising pressure in its rear. Upper-air winds at Medford and Spokane furnish a clue to the character of the LOW. Winds above the 8,000-foot level are always fresh to strong south or southwest at these stations during a definite cyclonic period. The type breaks up when a definite eastward movement of the LOW occurs, usually indicated by a shift of wind towards northerly points at high levels above Portland and Seattle. Illustrations are furnished by the weather maps of September 5 to 7, inclusive, 1931, and from July 6 to 10, inclusive, 1933. The latter example, in particular, shows that cessation of thunderstorm activity does not occur so long as pressure remains low over eastern Washington, but does occur immediately after a pronounced eastward movement of the Alberta LOW.
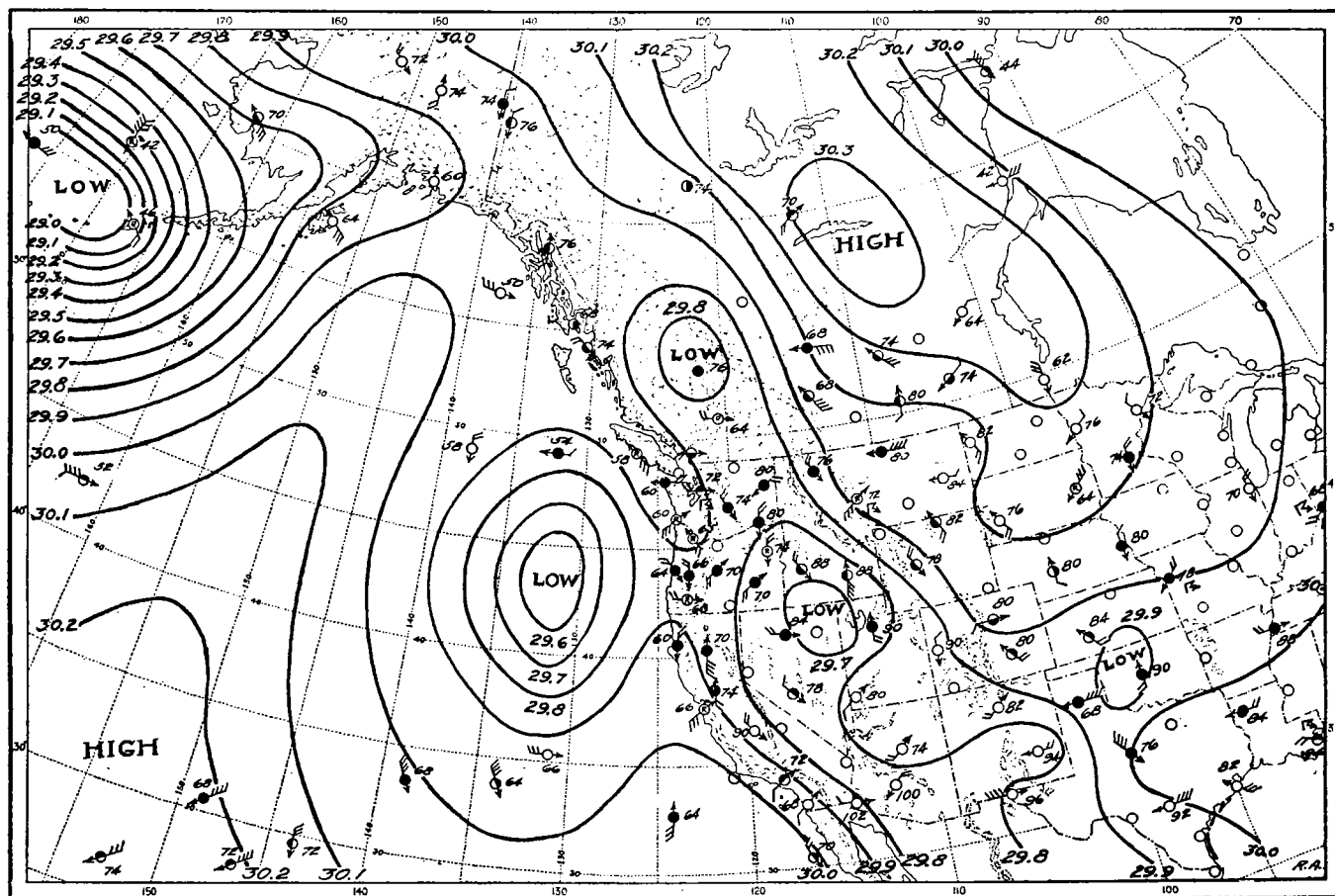

FIGURE 4.—June 14, 1931, 5 p. m. (one hundred and twentieth meridian): Conditions favorable for the development of "cyclonic" thunderstorms of type IIa in Oregon and Washington.
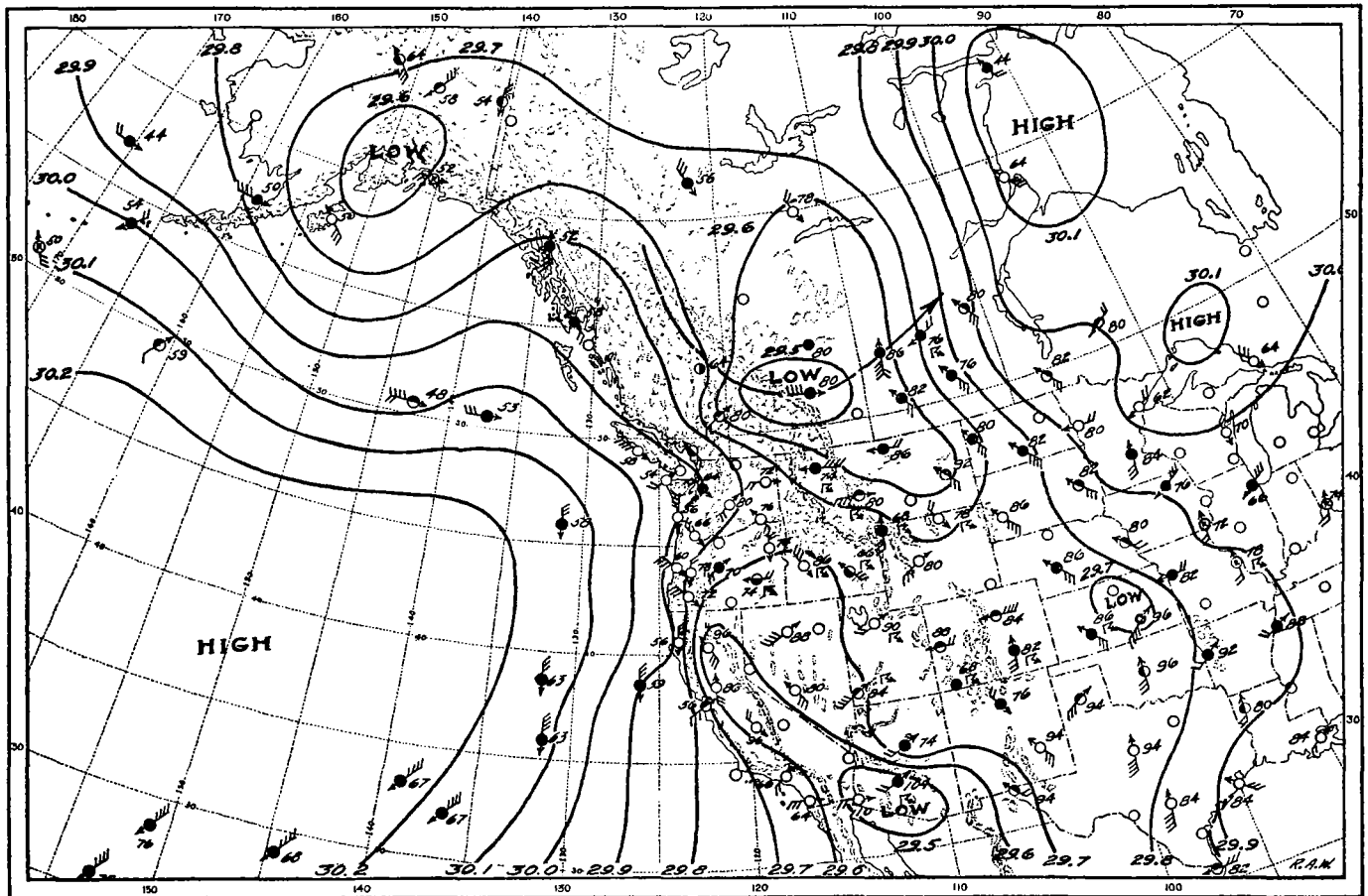
to Alberta, moving thence eastward across the Prairie Provinces. While they are centered over southern Alberta, or, less frequently, over the interior of southern British Columbia at the northern end of a trough extending southward to Mexico, thunderstorms develop over Oregon and Washington (fig. 5). In any examination of maps, however, care must be exercised to distinguish a true cyclonic development from the ordinary area of relatively low pressure which seems to exist at Kamloops so frequently during the prevalence of type Ib. This is, like the entire trough, largely a thermal phenomenon. The true cyclonic development in that area extends farther eastward and southeastward, is usually accompanied by a more characteristically cyclonic

PERCENTAGE OF THE PRESSURE-TYPE DAYS WHICH CAUSED THUNDERSTORMS

During the 10-year period there were certain occasions when one of the four pressure types occurred without thunderstorms being reported. To determine the percentage of occurrences of the pressure types which were not attended by thunderstorms, all occurrences of the types for the months of June, July, and August were tabulated for the 10 years. May and September were not used in this analysis because many of the lookout stations are not manned until the middle of June, nor after the middle of September, and reports of thunderstorms are incomplete. Of all the days on which one of

the four characteristic pressure types prevailed, only 15 percent had no thunderstorms reported. The annual percentage of thunderstorm verification ranged from 76 percent in 1929 to 95 percent in 1934. Since a considerable number of the unverified types were early in June, and since a great many of the remainder were days at the beginnings of more or less extended periods of the types attended by thunderstorm activity on the ensuing days, it is probable that the actual percentage of thunderstorm occurrence following a given pressure type is considerably higher than the 85 percent found in this tabulation. In fact it appears that, in general, thunderstorms result from the pressure types at least 90 percent of the time.

the southeast quadrant of a cyclone, while most frequent in May and September, never occurred in July or August. In contrast, type IIb thunderstorms, the southwest quadrant of a cyclone, were most frequent in July and least frequent in September. Type III thunderstorms, the transition type, were also most frequent in July and least frequent in May and September. Type I (considered as a unit) accounted for 67 percent of the total number of storm days, the remainder being equally divided between types II and III. Of the total of 625 days with thunderstorms reported during the 10-year period, 254, or 41 percent, were produced by a type Ib pressure condition.

FIGURE 5.—July 8, 1933, 5 p. m. (one hundred and twentieth meridian): Conditions favorable for the development of "cyclonic" thunderstorms of type IIb in Oregon and Washington.

Another tabulation to obtain the percentage of verification for each pressure type separately showed that 91 percent of the days with a type Ic distribution were attended by thunderstorms, 90 percent of type III, 86 percent of type Ib, 82 percent of type IIb, 77 percent of type Ia, and 40 percent of type IIa.

FREQUENCY OF TYPES

The total number of thunderstorm dates due to each type of pressure distribution was tabulated by months from May to September for the 10-year period 1925–34 to discover the month of greatest frequency for each type (table 2). August is the month of greatest thunderstorm occurrence with July only slightly behind. Type I thunderstorms (trough) were most frequent in August and least frequent in May. Type IIa thunderstorms,

TABLE 2.—*Monthly distribution of pressure-type days which produced thunderstorms in either Washington or Oregon, 1925 to 1934*

Month	Type I (trough)			Type II (cyclonic)		Type III (transition)	Type IV (border)	Total	Percent
	a (West of Cascades)	b (East of Cascades)	c Col	a (Southeast quadrant)	b (Southwest quadrant)				
	Number	Number	Number	Number	Number	Number	Number	Number	
May	4	15	11	9	14	13	0	66	11
June	15	36	26	2	18	24	0	121	19
July	14	79	21	0	22	33	0	169	27
August	19	96	21	0	18	18	0	172	27
September	14	28	18	12	9	14	2	97	6
Total	66	254	97	23	81	102	2	615	100
Percent	11	41	15	4	12	16	1	100	

RELATION OF PRESSURE TYPES TO THE EXTENT OF THE THUNDERSTORMS

In considering the thunderstorm days so far, no attempt has been made to distinguish between days with very few storms and days with widespread storm occurrence. Morris (6) has shown that the so-called "general"[2] storm leads all others as a cause of forest fires. Storms of this class, although of relatively infrequent occurrence, may account for as high as 92 percent of the total number of lightning-caused forest fires in a single year. For the period from 1925 to 1931, inclusive, covered in Morris' report, "general" thunderstorms accounted for 66 percent of all forest fires started, "intermediate" storms 24 percent, and "local" storms only 10 percent. For this reason, the relation of each pressure type to the extent of the resulting thunderstorms is important.

The inherent tendency of a given pressure type to produce widespread thunderstorms, or the odds in favor of widespread storms whenever a given pressure type appears, may be expressed by the number of "general" thunderstorm days developed by the type in relation to the total number of thunderstorm days developed by the type as shown in table 3.

The proportion of the widespread thunderstorms due to a given pressure type indicates the forest-fire risk of that type. This measure includes both the inherent tendency of the type to produce widespread thunderstorms and the type frequency. Table 4 shows that the trough east of the Cascade Range alone caused 58 percent of the "general" storms in the Pacific Northwest.

In the 10-year period 4 days were noted on which "general" thunderstorms occurred in all 3 subregions on the same day. Three of these were the result of type Ib pressure conditions and one of type Ic. During the same period, 2 days, both the result of type Ib conditions, occurred on which "intermediate" thunderstorms were reported from all three subregions.

On 17 days "general" thunderstorms occurred in two of the subregions simultaneously. Of these days, 9 were the result of type Ib pressure conditions, 4 the result of type IIb, 3 the result of type Ic, and 1 the result of type Ia. On 24 days "intermediate" thunderstorms occurred in 2 of the subregions simultaneously—14 of these resulted from type Ib pressure conditions, 5 from type IIb, 3 from type III, and 2 from type Ia.

TABLE 3.—*Percentage of the storms produced by each pressure type which became "general", "intermediate", or "local" in extent, 1925 to 1934*

| Date | Type I (trough) | | | Type II (cyclonic) | | Type III (transition) | Type IV (border) |
	a West of Cascades	b East of Cascades	c Col	a (Southeast quadrant)	b (Southwest quadrant)		
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
"General" thunderstorms___	5	14	12	0	13	2	0
"Intermediate" thunderstorms_____	30	24	14	8	24	12	0
"Local" thunderstorms_____	65	62	74	92	63	86	100
Basis: Total number of thunderstorm occurrences for all subregions_____	107	437	154	48	150	138	3

[2] A "general" storm, according to his definition, is one in which many small storms affect two-thirds or more of the area of any subregion, or in which one or more storms make a continuous track at least two-thirds the length of the subregion (the three subregions were: Western and central Oregon, the Blue Mountains of northeastern Oregon, and the Cascade Range and northeastern part of Washington).
A "local" storm is one in which there is only one or a few individual storms affecting a small area in any subregion.
An "intermediate" storm in any subregion is one in which the individual storms are more widespread than for a "local" but less extensive than for a "general" storm.

TABLE 4.—*Percentage of the "general" thunderstorms in each subregion produced by each pressure type, 1925 to 1934*

| Subregion | Type I (trough) | | | Type II (cyclonic) | | Type III (transition) | Type IV (border) | Number of cases |
	a West of Cascades	b East of Cascades	c Col	a (Southeast quadrant)	b (Southwest quadrant)			
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Washington_____	0	74	8	0	18	0	0	23
Western and central Oregon_____	8	54	19	0	14	5	0	37
Blue Mountains_____	4	52	21	0	21	2	0	48
All subregions combined_____	4	58	18	0	18	2	0	108

Type III. Transition thunderstorms.—This type is somewhat akin to Alexander's "combination type." High pressure from the Pacific is bulging in over the Pacific Northwest where winds have quite generally shifted to northerly points, and is displacing low pressure of type Ib or type IIb which formerly covered that region (fig. 6). It thus represents a break-up of some previous condition which has been productive of thunderstorms. It generally exists for but a single day, being definitely transitional in character. The fact that thunderstorms occur when pressure conditions indicate a cessation of them makes this type worthy of notice. During its prevalence one or more "fronts" appear to pass southeastward across Washington and Oregon, moving in the general southeastward flow of transitional Polar Pacific air. While usually of mild character, these "fronts" are sufficiently well marked to cause thunderstorms locally at points along their course, even after low-pressure conditions at the surface have ceased to be a factor. The HIGH need not push inland very far, but any definite pushing inland of the isobars, ordinarily over the Columbia River area, is an indication of this type. Upper air winds during the transition type have generally shifted to northerly points up to great heights above Portland and Seattle, but remain from southerly points, though of only moderate velocities, at Spokane and Medford. The type may come to an end in either of two ways: Usually high pressure is more or less firmly established by the following day, with typical anticyclonic conditions and fair weather. Upon occasion, however, after bulging inland, the HIGH retreats off the coast once again, and a low-pressure trough of type I is immediately reestablished. Weather maps of July 7, 1926, and August 29, 1927, are good illustrations of the transition-type pressure conditions. On the p. m. map of the former date, an obvious "front", as shown by the surface winds, extends south-southwestward between Spokane and Yakima.

Type IV. Border thunderstorms.—This type corresponds to Humphreys' (5) type "e"—"along the boundary between warm and cool waves", and is identical with Alexander's (2) of the same name. While it is not an uncommon type of pressure distribution during the winter months, being a mild form of Reed's "easterly type" (7), it is extremely rare during the fire-weather season. It occurred only once during the 10 years, 1925 to 1934, the same occasion noted by Alexander. For this reason it may be considered an almost negligible factor so far as fire risk is concerned.

An examination of the records was next made to determine whether "general" or "intermediate" thunderstorms were more likely to occur on the first day that a particular type sets in or on succeeding days. The "first day" was considered as the first day that a type was well

defined and definitely established, as shown by the a. m. weather chart. Conditions indicative of its development may have been evident for one or more days previous to that time, with scattered thunderstorms in some areas. It was found that the first or second day of existence was, in general, the most favorable for the development of scattered or extensive storms. Type Ib developed "general" storms most often on the second day, while type IIb developed them most often on the first day. All widespread storms due to type III occurred on the first day.

Another fact brought out by this analysis was that during any protracted and well-defined thunderstorm period, such as that of July 3 to 20, 1930, a forecaster would be justified in predicting at least "intermediate"

Northwest and a complete clearing out of the low-pressure trough takes place.

CONCLUSION

1. Examination of synoptic charts for the 10-year period from 1925 to 1934, inclusive, discloses that days of thunderstorm occurrence can be definitely related to four types of pressure distribution over the Pacific Coast States as follows: Type I. Trough thunderstorms; Type II. Cyclonic thunderstorms; Type III. Transition thunderstorms; Type IV. Border thunderstorms.

In general 85 percent of the pressure-type days produced thunderstorms.

2. Upper-air winds furnish an aid to the identification of the types and indicate the sources of air masses present during thunderstorm conditions.
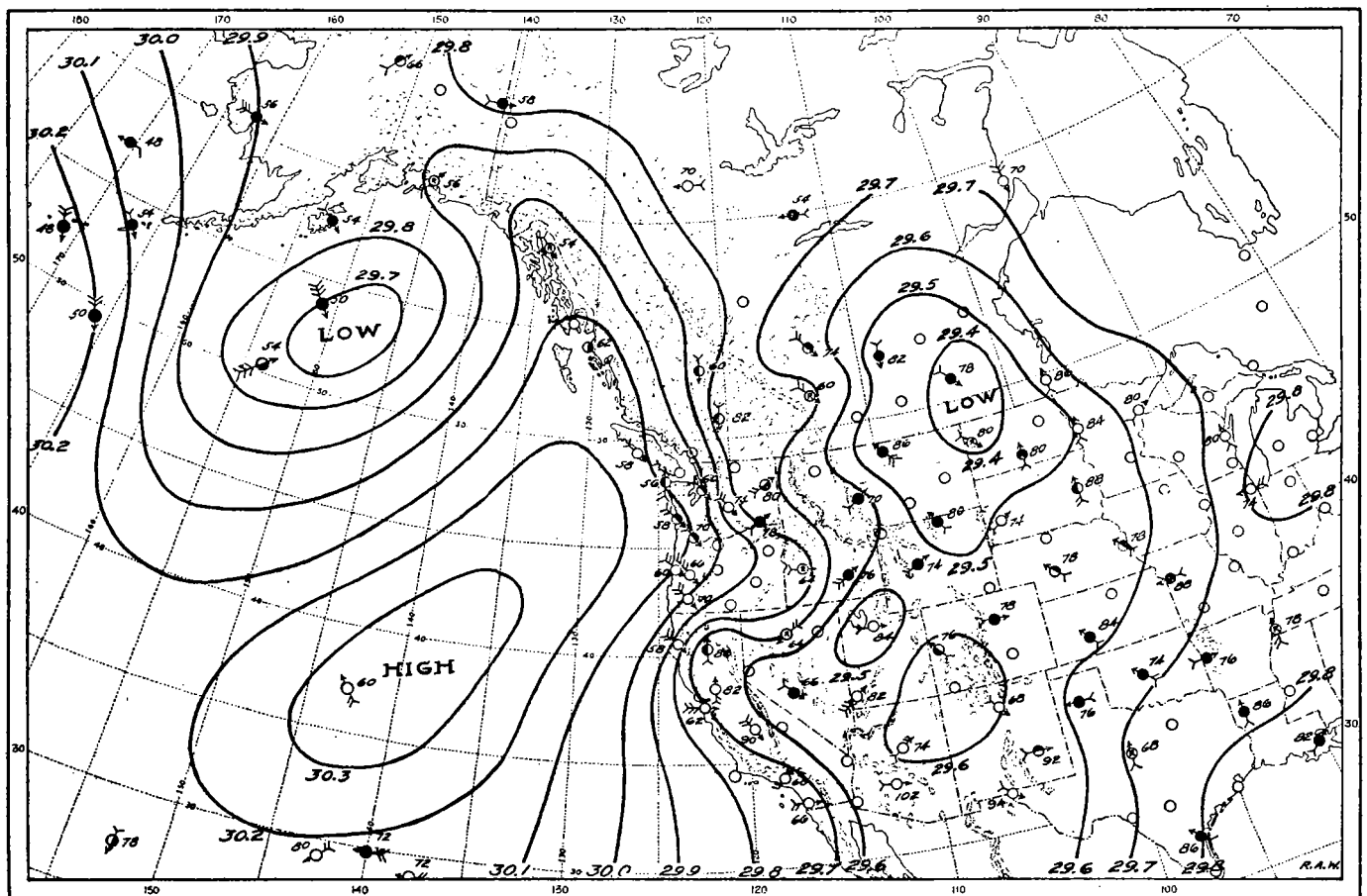

FIGURE 6.—July 27, 1926, 5 p. m. (one hundred and twentieth meridian): Conditions favorable for the development of "transition" thunderstorms of type III in Oregon and Washington.

storms every day until the period shows definite evidence of breaking up. During this 18-day period there were only 4 days that "general" or "intermediate" thunderstorms did not occur in one or more of the subregions. This was found to be true of all other protracted periods, such as that of July 22 to August 11, 1927, and August 17 to 29 of the same year. During such periods type Ib conditions are the dominant factors, occasionally being modified to type Ia or Ic, and, briefly, by the appearance of a cyclonic storm at the northern end of the trough, to type IIb. It might then almost be said to be the rule that when a type I trough condition becomes firmly established during midsummer, dangerous thunderstorm conditions are likely after the first or second day in any of the subregions. They are likely to continue, with varying intensity, until the pressure rises decidedly over the Pacific

3. Storms resulting from type I are the most frequent and, because of their tendency to be widespread and to follow dry weather conditions, are the most dangerous. Although storms from the southwest quadrant of a cyclone (type IIa) are as frequently widespread as those from type I, they are usually accompanied by precipitation to a greater extent than those of the other types, and for this reason are somewhat less dangerous. Storms of type III are generally confined to a single day and are most often local in character. Storms of type IV are so infrequent as to be a negligible factor.

4. During the persistence of a trough east of the Cascade Range "intermediate" or "general" thunderstorms are more likely on the second day of the well-marked occurrence of the type than on the first day. For either a trough west of the Cascades or a Col, "intermediate" or

"general" thunderstorms are most liable to occur on either the first or second day. Once having been established, these conditions are likely to continue until a definite replacement of low pressure over the interior of Oregon and Washington by high pressure from the Pacific has taken place.

5. While the types identified in this investigation furnish a practically certain indication of thunderstorms on the national forests of Oregon and Washington, they do not furnish positive indications of whether or not the resulting thunderstorm days will be "intermediate" or "general" in character. It is believed, however, that with the more or less general indications furnished by the type maps and the use of additional aids, such as those furnished in Stevens' report (8), upper air data, dew-point data, etc., an attempt might be made to give somewhat more localized and closely-defined forecasts than have been possible heretofore.

LITERATURE CITED

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EFFECT OF INSOLATION ON SOUNDING-BALLOON METEOROGRAPH TEMPERATURE ELEMENTS

By CHARLES M. LENNAHAN

In view of the increasing interest in stratosphere observations, the recent conclusions reached independently by J. C. Ballard [1] and by L. H. G. Dines [2] regarding the effect of insolation on the temperature element of balloon meteorographs, are worthy of attention.

Dines used 155 soundings which he grouped by months and then subclassified according to day and night, and to ascent and descent. Many of the daytime observations were made near 7h., G. M. T., which corresponds to about 7 a. m., local time in England. The night *descents* were taken as the standard.

Ballard considered about 200 soundings which were grouped according to the three times, 7 a. m., noon, and midnight, C. S. T., for ascents only. The midnight *ascent* was taken as the standard for this study. Ballard's 7 a. m. group corresponds fairly well to Dines daytime ascent group.

Both investigations agree on the following points:

(1) The major part of the insolation effect is a result of the solar rays striking the temperature element, either directly or after one or more reflections inside the ventilating tube.

(2) Diurnal variation and change of air mass are eliminated as possible causes of the discrepancy between daytime and nighttime observations.

(3) The effect of insolation is small in the troposphere compared to its effect in the stratosphere.

(4) 10 kilometers is the critical height above which the error due to insolation becomes excessive.

(5) The poor ventilation resulting from the small density of the air at high altitudes is responsible for the pronounced effect of solar radiation in the stratosphere, and accounts for the fact that the insolation effect increases with height.

(6) The heating of the instrument case, the balloon, and the frame holding the meteorograph are minor sources of error.

The remarkable agreement between the results of the two investigations is shown in the following table of values taken from the published mean error curves:

Dines daytime ascents	Height, kilometer	Ballard 7 a. m. ascents
°C.		°C.
1.0	[1] 8	0.5
1.5	[1] 10	1.0
2.0	[1] 12	2.0
3.0	14	3.0
4.0	16	4.0
5.5	18	5.5
6.0	19	6.0

[1] Dines limited his study to the region between 13 and 19 kilometers, but he extrapolated the curve to lower levels.

Two circumstances are especially significant for this agreement: The first is that the Dines meteorograph was used in England, whereas the Fergusson instrument was used by Ballard. The second is that different methods were used to obtain the results.

The one point of difference in the conclusions from the two studies is in respect to the importance of the angular height of the sun on the effect of solar radiation in the stratosphere. Dines states that the altitude of the sun makes little difference, and that he could find no reason to believe that the recorded temperatures at noon are higher than at other daytime hours; whereas Ballard finds a definite increase in the insolation effect, and consequently an increase in recorded temperature, between the 7 a. m. and the noon ascents.

Both investigations indicate that if the temperature element could be adequately shielded from insolation, the major portion of the error in daytime observations would be eliminated.